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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
10/628,964	07/30/2003	Siddheswar Chaudhuri	TELM-03-001	6182

7590 04/20/2007

Jennifer Earley-Patent Administrator
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EXAMINER	
NGO, NGUYEN HOANG	
ART UNIT	PAPER NUMBER
2616	

SHORTENED STATUTORY PERIOD OF RESPONSE	MAIL DATE	DELIVERY MODE
3 MONTHS	04/20/2007	PAPER

Please find below and/or attached an Office communication concerning this application or proceeding.

If NO period for reply is specified above, the maximum statutory period will apply and will expire 6 MONTHS from the mailing date of this communication.

Office Action Summary	Application No. 10/628,964	Applicant(s) CHAUDHURI ET AL.	
	Examiner Nguyen Ngo	Art Unit 2616	

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address --

Period for Reply

A SHORTENED STATUTORY PERIOD FOR REPLY IS SET TO EXPIRE 3 MONTH(S) OR THIRTY (30) DAYS, WHICHEVER IS LONGER, FROM THE MAILING DATE OF THIS COMMUNICATION.

- Extensions of time may be available under the provisions of 37 CFR 1.136(a). In no event, however, may a reply be timely filed after SIX (6) MONTHS from the mailing date of this communication.
- If NO period for reply is specified above, the maximum statutory period will apply and will expire SIX (6) MONTHS from the mailing date of this communication.
- Failure to reply within the set or extended period for reply will, by statute, cause the application to become ABANDONED (35 U.S.C. § 133). Any reply received by the Office later than three months after the mailing date of this communication, even if timely filed, may reduce any earned patent term adjustment. See 37 CFR 1.704(b).

Status

1)☒ Responsive to communication(s) filed on 30 July 2003.

2a)☐ This action is **FINAL**. 2b)☒ This action is non-final.

3)☐ Since this application is in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 11, 453 O.G. 213.

Disposition of Claims

4)☒ Claim(s) 1-19 is/are pending in the application.

4a) Of the above claim(s) _____ is/are withdrawn from consideration.

5)☐ Claim(s) _____ is/are allowed.

6)☒ Claim(s) 1-19 is/are rejected.

7)☐ Claim(s) _____ is/are objected to.

8)☐ Claim(s) _____ are subject to restriction and/or election requirement.

Application Papers

9)☐ The specification is objected to by the Examiner.

10)☐ The drawing(s) filed on _____ is/are: a)☐ accepted or b)☐ objected to by the Examiner.

Applicant may not request that any objection to the drawing(s) be held in abeyance. See 37 CFR 1.85(a).

Replacement drawing sheet(s) including the correction is required if the drawing(s) is objected to. See 37 CFR 1.121(d).

11)☐ The oath or declaration is objected to by the Examiner. Note the attached Office Action or form PTO-152.

Priority under 35 U.S.C. § 119

12)☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).

a)☐ All b)☐ Some * c)☐ None of:

1.☐ Certified copies of the priority documents have been received.

2.☐ Certified copies of the priority documents have been received in Application No. _____.

3.☐ Copies of the certified copies of the priority documents have been received in this National Stage application from the International Bureau (PCT Rule 17.2(a)).

* See the attached detailed Office action for a list of the certified copies not received.

Attachment(s)

1) ☒ Notice of References Cited (PTO-892)
2) ☐ Notice of Draftsperson's Patent Drawing Review (PTO-948)
3) ☐ Information Disclosure Statement(s) (PTO/SB/08) Paper No(s)/Mail Date _____.
4) ☐ Interview Summary (PTO-413) Paper No(s)/Mail Date. _____ .
5) ☐ Notice of Informal Patent Application
6) ☐ Other: _____.

DETAILED ACTION

Claim Rejections - 35 USC § 102

1. The following is a quotation of the appropriate paragraphs of 35 U.S.C. 102 that form the basis for the rejections under this section made in this Office action:

> A person shall be entitled to a patent unless –
>
> (b) the invention was patented or described in a printed publication in this or a foreign country or in public use or on sale in this country, more than one year prior to the date of application for patent in the United States.

2. Claims 1-4, and 13 are rejected under 35 U.S.C. 102(b) as being anticipated by Stochastic Approaches to compute Shared Mesh Restored Lightpaths in Optical Network Architectures by Bouillet, E., Labourdette, J-F, Ellinas, G., Ramamurthy, R., and Chaudhuri, S., hereafter referred to as Bouillet.

Regarding claim 1, Bouillet discloses a method of selecting paths (set-up the path, page 804,left column, paragraph 5) comprising the steps of:

a) computing a plurality of first shortest paths from a source point to a destination point each including of a serial chain of at least one communications link (compute k-shortest paths, page 804, left column, paragraph 5);

b) selecting K first shortest paths from the plurality (compute k-shortest paths);

c) ordering the selected K first shortest paths from shortest to longest (Sort the paths by length and denominate them w1 to wk, page 804, left column, paragraph 5);

d) for each first shortest path of K (for each shortest path wi, page 804, left column, paragraph 5),

i) computing the cost of the first shortest path as substantially equal to the combined cost of the links included in the first shortest path (compute the shortest path si using the metric defined in parts, (page 804, left column, paragraph 5);

ii) selecting a lowest estimated cost second shortest path from the remainder of the elements of K, where the estimated cost of the second shortest path is computed as substantially equal to the combined estimated cost of the links included in the second shortest path and the cost of a link corresponds to the cost of using the link scaled by a probability that the link can be shared by the second shortest path and a path already provisioned using a channel of the link (to each edge that shares a SRG with wi assign infinite weight and for each edge with reserved channel, set weight to cost of edges time the probability that no reserved channel is shareable, page 804, left column, paragraph 5);

e) selecting the lowest estimated combined cost first and second shortest path pair (select the minimum cost path pair, page 804, left column, paragraph 5).

It should further be noted that Applicant specifically states "Our method is described by Bouillet ... in a paper entitled "Stochastic Approaches to Route Shared Mesh Restored Lightpaths in Optical Mesh Networks, " in the Proceedings of the Conference on

Computer Communications, in June 2002, on page 801 through 807", in the specification in paragraph [020].

Regarding claim 2 Bouillet discloses the method according to claim 1, wherein for a second shortest path, the cost of a link is estimated by;

a) assigning an infinite cost to a link included in an associated first shortest path;

b) assigning an infinite cost to a link that traverses at least one shared-risk-group (SRG) traversed by an associated first shortest path ((i) to each edge that shares a SRG with wi or has neither available channel nor reserved channel, assign infinite weight, page 804, left column, paragraph 5);

c) assigning to a link not having an available shared protection channel a cost substantially equal to the cost of allocating an additional shared protection channel to the link ((ii) for each edge without a reserved channel, set weight to cost of edge, page 804, left column, paragraph 5);

d) estimating for a link having at least one available shared protection channel a cost corresponding to the cost of using the link scaled by a probability that the link can be shared by the second path under consideration and no backup paths already provisioned using the link ((iii) for each edge with reserved channel, set weight to cost of edge times the probability that no reserved channel is shareable, page 804, left column, paragraph 5).

Regarding claim 3, Bouillet discloses the method of claim 2 wherein the probability that the link can be shared by the second path under consideration and no backup path already provisioned using the link is determined according to a method comprising;

a) creating a variable M, and assigning as its value the number of available shared protection channels in the link (M bins are the reserved channels, page 803, right column, paragraph 2);

b) for each j from 1 to N;

i) creating an array of N elements, SRGj, consisting of the N SRGs traversed by a proposed primary path (N SRGs traversed by the primary path for which a reserved channel is sought, page 803, right column, paragraph 2);

ii) creating an array of N elements, nj, consisting of the number of times SRGj is traversed by a primary path protected by a backup path already provisioned using channels of the link (page 803, right column, paragraph 2);

c) computing a probability, p, that one available shared protection channel of a link can be shared by a second shortest path and one backup path already provisioned sing the channel as p=]lj(1-nj/M), for j from 1 to N (page 803, right column, paragraph 1);

d) computing a probability, P, that no available shared protection channel of a link can be shared by a second shortest path with a backup path already provisioned using a channel of the link as P=(1-p)M, page 803, right column, paragraph 2).

Regarding claim 4, Bouillet discloses the method according to claim 1, wherein the lowest cost path pair is selected according to a method comprising;

a) defining an array of K elements, wi, where i ranges from 1 to K, including the ordered K first selected paths;

b) defining an array of K elements, si, where i ranges from 1 to K, including the K second shortest paths associated with the ordered K first selected paths;

c) defining a set, K, comprised of elements {wi,si}, where i ranges from 1 to K;

d) computing the combined estimated cost of the elements of set K, and ordering the elements from lowest combined estimated cost to highest combined estimated cost;

e) selecting the lowest combined estimated cost path pair in set K (page 804 left column).

Regarding claim 13, Bouillet discloses a shared mesh protection network wherein paths are provisioned according to a method comprising;

a) generating a list of at least one candidate pair of paths including one primary path and one associated backup path between a source network element and a destination network element (compute k-shortest paths, page 804, left column, paragraph 5);

b) selecting a lowest estimated path pair from the list where the cost of the primary path is substantially equal to the cost of the network resources included in the primary path and the estimated cost of a backup path corresponds to the cost of the network resources included in the backup path scaled by the probability that existing network resources can be shared by the backup path (select minimum cost path pair, page 804, left column, paragraph 5);

c) using signaling to attempt to establish the selected path pair, use signaling to set-up the path, page 804, left column, paragraph 5);

d) eliminating the selected path pair from the list if it can not be established and attempting to establish a new lowest estimated cost path pair (page 804, left column, paragraph 5);

e) returning an error signal to a network operator if no candidate path pair from the list can be allocated (if no path can be found return NO-PATH, page 804, left column, paragraph 5).

Claim Rejections - 35 USC § 103

3. The following is a quotation of 35 U.S.C. 103(a) which forms the basis for all obviousness rejections set forth in this Office action:

> (a) A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains. Patentability shall not be negatived by the manner in which the invention was made.

4. The factual inquiries set forth in *Graham* **v.** *John Deere Co.*, 383 U.S. 1, 148 USPQ 459 (1966), that are applied for establishing a background for determining obviousness under 35 U.S.C. 103(a) are summarized as follows:

1. Determining the scope and contents of the prior art.
2. Ascertaining the differences between the prior art and the claims at issue.
3. Resolving the level of ordinary skill in the pertinent art.
4. Considering objective evidence present in the application indicating obviousness or nonobviousness.

5. Claims 5-12 are rejected under 35 U.S.C. 103(a) as being unpatentable over Stochastic Approaches to compute Shared Mesh Restored Lightpaths in Optical Network Architectures by Bouillet, E., Labourdette, J-F, Ellinas, G., Ramamurthy, R., and Chaudhuri, S., in view of Wu et al. (US 2004/0042406), hereafter referred to as Bouillet and Wu.

Regarding claim 5, Bouillet discloses a method of selecting paths comprising the steps of:

a) creating a first graph representing a network having a topology containing network elements interconnected by communications links wherein each network represented by a vertex and each communication link interconnecting adjacent network elements is represented by an edge, the first graph containing a source vertex corresponding to an ingress network element and a destination vertex corresponding to an egress network element (topology represented as a graph G(V,E), page 804, left column, paragraph 3);

b) using the first graph to calculate a plurality of paths between the source and destination vertices (bi-directional lightpaths from A to Z, page 804, left column, paragraph 4);

c) selecting K first shortest paths between source vertex and destination vertex (compute k-shortest paths, page 804, left column, paragraph 5);

d) for each first shortest path;

i) computing the cost of the first shortest path (assign weight, page 804, left column, paragraph 5);

iii) Selecting a lowest estimated cost second shortest path from source vertex to destination vertex wherein the estimated cost of the second shortest path is substantially equal to the combined estimated costs of the

edges comprising the second shortest path and the estimated cost of an edge corresponds to the cost of using the edge scaled a probability that the edge can be shared by the second shortest path and a path already provisioned using a channel of the edge (page 804, left column, paragraph 5);;

e) selecting the lowest estimated combined cost first and second shortest path pair (select minimum cost path pair, page 804, left column, paragraph 5).

Bouillet however fails to specifically disclose creating a second graph substantially based on the first graph wherein the second graph includes edges and estimated edge costs and an edge associated with the first shortest path is modified from the first graph. Wu however discloses a method of generating a network graph from network information and calculating a primary explicit route through the network from the generated network graph (page 1 [0012]). It would thus be obvious to a person skilled in the art at the time the invention was made to incorporate the concept of generating a second graph based on network information (first graph information) which includes edge costs as disclosed by Wu into the Stochastic Approaches to Route Shared Mesh Restored Lightpaths in Optical Mesh Networks as disclosed by Bouillet in order to efficiently calculate paths through the network from source to destination.

Regarding claim 6, the combination of Bouillet and Wu, more specifically Wu discloses the method according to claim 5 wherein an edge associated with the first shortest path is modified by removing it from the second graph (the links not meeting the specified constraints got the path are eliminated from the graph, page 1[0012]).

Regarding claim 7, the combination of Bouillet and Wu, more specifically Bouillet discloses a method according to claim 5 wherein an edge associated with the first shortest path is modified by setting its estimated edge cost to a very high value (weight, page 804, left column, paragraph 5).

Regarding claim 8, the combination of Bouillet and Wu, more specifically Bouillet discloses a method according to claim 5 wherein an edge associated with the first shortest path is modified by setting its estimated edge cost to an infinite value (infinite weight, page 804, left column, paragraph 5).

Regarding claim 9, the combination of Bouillet and Wu, more specifically Bouillet discloses the method according to claim 5 wherein the K first shortest paths are ordered from lowest cost to highest cost and assigned to elements w, of set K, where i ranges from 1 to K (page 804, left column, paragraph 5).

Regarding claim 10, the combination of Bouillet and Wu, more specifically Bouillet the method according to claim 5, wherein for each first shortest path a least estimated cost

second shortest path is chosen from the second graph and for each second shortest path in a second graph, the cost of a link is estimated according to a method comprising;

i) assigning an infinite cost to an edge that traverses at least one SRG traversed by the first shortest path ((i) to each edge that shares a SRG with wi or has neither available channel nor reserved channel, assign infinite weight, page 804, left column, paragraph 5);

ii) assigning to an edge without an available shared protection channel a cost substantially equal to the cost of adding an additional shared protection channel to the edge ((ii) for each edge without a reserved channel, set weight to cost of edge, page 804, left column, paragraph 5);

iii) estimating for an edge having at least one available shared protection channel a cost corresponding to the cost of using the edge scaled by probability that the edge can be shared by the second path under consideration and no backup paths already provisioned using the edge ((iii) for each edge with reserved channel, set weight to cost of edge times the probability that no reserved channel is shareable, page 804, left column, paragraph 5).

Regarding claim 11, the combination of Bouillet and Wu, more specifically Bouillet discloses the method of claim 10 wherein the probability that an edge can be shared by

the second path under consideration and no backup path already provisioned using channels of an edge is estimated by;

a) creating a variable M, and assigning as its value to the number of available shared protection channels in the edge (M bins are the reserved channels, page 803, right column, paragraph 2);

b) for each j from 1 to N;

i) creating an array of N elements, SRGj, consisting of the N SRGs traversed by a proposed primary path (N SRGs traversed by the primary path for which a reserved channel is sought, page 803, right column, paragraph 2);

ii) creating an array of N elements, nj, consisting of the number of times SRGj is traversed by a primary path protected by a backup path already provisioned using channels of the link (page 803, right column, paragraph 2);

c) computing a probability, p, that one available shared protection channel of a link can be shared by a second shortest path and one backup path already provisioned sing the channel as p=]lj(1-nj/M), for j from 1 to N (page 803, right column, paragraph 1);

d) computing a probability, P, that no available shared protection channel of a link can be shared by a second shortest path with a backup path already provisioned using a channel of the link as P=(1-p)M, page 803, right column, paragraph 2).

Regarding claim 12, the combination of Bouillet and Wu, more specifically Bouillet discloses the method of claim 5, wherein a lowest estimated combined cost first and second shortest path pair is selected according to a method comprising;

a) creating a set, S, with K elements {wi,si}, where i ranges from 1 to K, including the K first shortest paths, wi, and K associated selected second shortest paths, si (Set S, page 804, left column, paragraph 5);.

b) for each first shortest path, wi, where i ranges from 1 to K;

ii) computing a cost substantially equal to the combined cost of the links included in the first shortest path;

ii) computing an estimated cost for the associated selected second shortest path substantially equal to the combined estimated cost of the links comprising the selected second shortest path page 804, left column, paragraph 5);

d) selecting the lowest combined estimated cost path pair (select minimum cost pair, page 804, left column, paragraph 5).

Bouillet however fails to specifically disclose ordering the elements of set S from lowest combined estimated cost to highest combined estimated cost. However this procedure would have been obvious to a person skilled in the art at the time the invention was made in order to efficiently determine the lowest combined estimated cost path pair in a reliable manner.

6. Claims 14- 19 are rejected under 35 U.S.C. 103(a) as being unpatentable over Stochastic Approaches to compute Shared Mesh Restored Lightpaths in Optical Network Architectures by Bouillet, E., Labourdette, J-F, Ellinas, G., Ramamurthy, R., and Chaudhuri, S., in view of Ishibashi et al. (US 2003/0147352), hereafter referred to as Bouillet and Ishibashi.

Regarding claim 14, Bouillet fails to specifically disclose the network of Claim 13 wherein path provisioning is controlled by the source network element and signaling is used between the source network element and each network element in a proposed pair of primary and backup paths to establish links between adjacent network elements. However this is a well-known technique known in the art. Ishibashi further discloses that when a path setup request is generated from the source, the network calculates a pair of SRLF- disjoint working and protection paths and that a signaling message is then

transmitted through the network and that bandwidth reservation is performed for both working and protection paths (page 1 [0008]). It would thus be obvious at the time the invention was made to incorporate the well known concept of establishing primary and backup paths between adjacent network nodes through signaling as disclosed by Ishibashi into the Stochastic Approaches to Route Shared Mesh Restored Lightpaths in Optical Mesh Networks as disclosed by Bouillet in order to efficiently establish primary and backup paths through a network.

Regarding claim 15, the combination of Bouillet and Ishibashi further discloses the network of claim 14, wherein said signaling is comprised of the steps of;

a) for each network element in the primary path, sending from the source network element to the network element a request for the network element to establish a link with adjacent network elements (signaling message transmitted through the network and bandwidth reservation is performed for the working path, page 1 [0008]);

b) for each network element in the backup path, sending from a source network element to the network element a request for the network element to establish a link with adjacent network elements (signaling message transmitted through the network and bandwidth reservation is performed for the protection path, page 1 [0008]);

c) for each network element in the primary path that can not establish a link to an adjacent network element, sending from the network element to the source network element an error signal (rejected request, page 6 [0081]);

d) for each network element in the primary path that can establish a link to an adjacent network element, sending from the network element to the source network element a valid link signal (page 7 [0097]);

It should be noted that the steps of establishing links in a network via error signals and valid link signals is a well known concept known in the art.

Regarding claim 16, the combination of Bouillet and Ishibashi discloses the network of Claim 13 wherein the network has a single network controller and signaling between the controller and network elements is used to provision primary and backup paths (network controller of figure 1 and page 6 [0082]).

Regarding claim 17, the combination of Bouillet and Ishibashi fail to disclose the specific limitation of reallocation of existing network resources is initiated at any time. However this would have been obvious to a person skilled in the art at the time the invention was made as this is simply a network parameter informing when reallocation should be determined.

Regarding claim 18, the combination of Bouillet and Ishibashi fail to disclose the specific limitation reallocation of existing network resources is initiated at each request of new communications service. However this would have been obvious to a person skilled in the art at the time the invention was made, as this is simply a network parameter informing when reallocation should be determined.

Regarding claim 19, the combination of Bouillet and Ishibashi fail to disclose the specific limitation reallocation of existing network resources is initiated at regularly scheduled intervals. However this would have been obvious to a person skilled in the art at the time the invention was made, as this is simply a network parameter informing when reallocation should be determined.

Conclusion

7. The prior art made of record and not relied upon is considered pertinent to applicant's disclosure.

a) Pieda et al. (US 2002/0191545), Methods And Apparatus For Selecting Multiple Paths Taking Into Account Shared Risk.

b) Yagyu (US 20030174644), Routing Control Method And Routing Control Apparatus For The Same.

Any inquiry concerning this communication or earlier communications from the examiner should be directed to Nguyen Ngo whose telephone number is (571) 272-8398. The examiner can normally be reached on Monday-Friday 7am - 3:30 pm.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Wing Chan can be reached on (571) 272-7493. The fax phone number for the organization where this application or proceeding is assigned is 571-273-8300.

Information regarding the status of an application may be obtained from the Patent Application Information Retrieval (PAIR) system. Status information for published applications may be obtained from either Private PAIR or Public PAIR. Status information for unpublished applications is available through Private PAIR only. For more information about the PAIR system, see http://pair-direct.uspto.gov. Should you have questions on access to the Private PAIR system, contact the Electronic Business Center (EBC) at 866-217-9197 (toll-free). If you would like assistance from a USPTO Customer Service Representative or access to the automated information system, call 800-786-9199 (IN USA OR CANADA) or 571-272-1000.

*** N.N.
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SUPERVISORY PATENT EXAMINER

Notice of References Cited	Application/Control No. 10/628,964	Applicant(s)/Patent Under Reexamination CHAUDHURI ET AL.	
	Examiner Nguyen Ngo	Art Unit 2616	Page 1 of 1

U.S. PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	Classification
*	A	US-2004/0042406	03-2004	Wu et al.	370/238
*	B	US-2003/0147352	08-2003	Ishibashi et al.	370/248
*	C	US-2002/0191545	12-2002	Pieda et al.	370/238
*	D	US-2003/0174644	09-2003	Yagyu, Tomohiko	370/228
	E	US-			
	F	US-			
	G	US-			
	H	US-			
	I	US-			
	J	US-			
	K	US-			
	L	US-			
	M	US-			

FOREIGN PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Country	Name	Classification
	N					
	O					
	P					
	Q					
	R					
	S					
	T					

NON-PATENT DOCUMENTS

*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
	U	Bouillet, E., Labourdette, J-F, Ellinas, G., Ramamurthy, R., and Chaudhuri, S., Stochastic Approaches to compute Shared Mesh Restored Lightpaths in Optical Network Architectures 23-27 June 2002, Infocom 2002, Volume 2, pages 801-807.
	V	
	W	
	X	

*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)
Dates in MM-YYYY format are publication dates. Classifications may be US or foreign.

Stochastic Approaches to Compute Shared Mesh Restored Lightpaths in Optical Network Architectures

Eric Bouillet, Jean-François Labourdette, Georgios Ellinas, Ramu Ramamurthy, Sid Chaudhuri

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Abstract: In this paper we assess the benefits of using statistical techniques to ascertain the shareability of protection channels when computing shared mesh restored lightpaths. Current deterministic approaches require a detailed level of information proportional to the number of active lightpaths, and do not scale well as traffic demands and network grow. With the proposed approach we show that less information, independent of the amount of traffic demand, is sufficient to determine the shareability of protection channels with remarkable accuracy. Experiments also demonstrate that our approach yields faster computation times with no significant penalty in terms of capacity usage.

Index terms: Optical networks, Optical Switching, Mesh Protection, Stochastic Algorithm, Performance Analysis.

A. INTRODUCTION

Dense Wavelength Division Multiplexed (DWDM) mesh network infrastructures that route optical connections (lightpaths) using intelligent optical cross-connects (OXCs) have emerged as the technology of choice to implement next generation data[1]. In these architectures a single piece of equipment is capable of transferring tens of terabits per second. This equipment is continuously exposed to multifarious risks of breakdown, either due to human-induced mishaps, or to equipment malfunctions. In order to guarantee service persistence in such circumstances it is common for a carrier to reserve spare bandwidth on alternate paths, so that a service affected by a failure along its primary lightpath can be rapidly restored using the reserved bandwidth. Among the possible schemes for provisioning backup paths, dedicated protection and mesh restoration seem to be the most appropriate approaches in the context of DWDM networks [2][3][4].

In dedicated protection, the lightpath provisioning algorithm computes and establishes simultaneously the primaries and their protection paths. During normal operation mode, both paths carry the optical signal and the egress selects the best copy of the two. The concept of Shared Risk Group (SRG) was introduced to select the paths so that they will not be affected by a single failure[5][6]. An SRG expresses the relationship that associates optical lines (or possibly other optical components) with a single failure. It may consist of all the optical lines in a single fiber, or the optical lines through all the fibers wrapped in the same cable, or all the optical lines traversing the same conduit. Since a fiber can traverse several conduits, an optical line may belong to several SRGs. It suffices that a primary and its backup path are SRG disjoint to ensure that at least one path survives any single failure.

As in dedicated protection, shared mesh restored paths are predefined, except that the cross-connections along the paths are not created until a failure occurs. During normal operation modes the spare optical lines reserved for protection are not used. We refer to such channels as reserved (for restoration) channels. Since the capacity is only "soft reserved", the same optical line can be shared to protect multiple lightpaths. There is a condition though that two backup lightpaths may share a reserved channel only if their respective primaries are mutually Shared Risk Group (SRG) disjoint, so that a failure does not interrupt both primary paths. If that happened, there would be contention for the reserved channel and at most only one of the two lightpaths would be successfully restored. Two lightpaths, or their protection, are said to be mutually compatible, if they are not affected by the same failure. If not, they are incompatible. Figure 1 (for normal mode) and Figure 2 (for restoration mode) illustrate an example of mesh restoration. The network consists of four client nodes (A to D) and two demands (AB and CD) accommodated across an eight node optical network (S to Z). The dashed lines represent channels reserved for protection. Using the routing of Figure 1, demands AB and CD are compatible with respect to SRG-failures and thus their protection share a single optical line in link S-T, one less than would be required in dedicated protection. Upon failure as depicted in Figure 2, the egress and egress nodes of the disconnected paths (X and Z) emit a request to the switches along the protection paths (S and T) to establish the cross-connections for that path. Once the cross-connections are established, each ingress and egress node restores the connection to the new path. This architecture requires fewer resources than in dedicated protection, but the restoration involves more processing to signal and establish the cross-connections along the restoration path.

They are two policies to assign reserved channels to restoration paths[7]: A failure dependent strategy assigns the reserved channels in real time after failure occurrence on a first-come first-serve basis depending on availability. A proper spare channel-provisioning scheme reserves enough channels so that all lightpaths can be restored for every type of failure. A failure independent strategy assigns the reserved channels at the time of lightpath provisioning prior to failure occurrence. One advantage of the failure independent strategy over the failure dependent is that during lightpath restoration the switches on the protection paths immediately and individually cross-connect to predetermined channels, based uniquely on the identifier of the lightpath being restored. For the scope of this study the failure independent strategy is used.

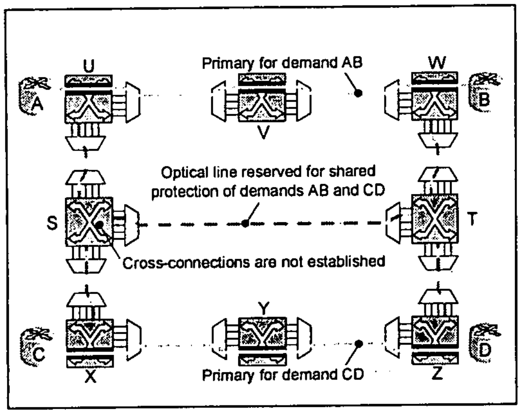

Figure 1. Mesh Restoration, before failure

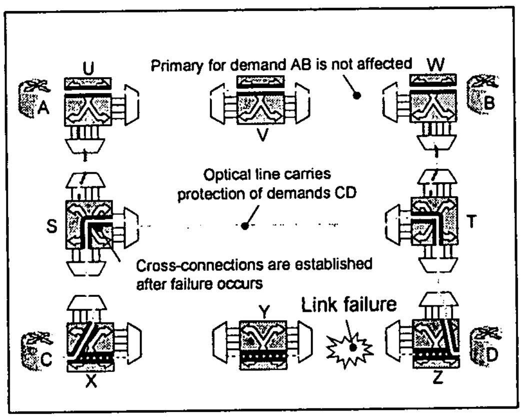

Figure 2. Mesh Restoration, upon failure of fiber Y-Z

Now, consider the online problem of provisioning a mesh-restored lightpath using a centralized Route Computation Module (RCM.) Since this problem is proved to be NP-complete if minimization of the total capacity usage (working plus protection) is sought, a possible approach is to enumerate a list of K minimum cost primary paths and for every one of them compute the corresponding minimum cost restoration path. The RCM then returns the pair of paths with the lowest aggregated cost. The cost of a pair is the cost of the channels along both paths, excluding the cost of (preexisting) shareable reserved channels along the backup path. Given a primary path, we compute the minimum cost backup-path by: (i) setting the cost of the fibers (SRGs) traversed by the primary path to ∞, (ii) setting the cost of fibers with shareable channels to a constant $\varepsilon \ll 1$, (iii) run a shortest path algorithm using the modified fiber cost metric. Step (i) and (ii) respectively ensure that primary and backup paths are SRG-diverse, and that the minimum cost backup path is found using shareable reserved channels whenever possible. In the following we are interested in step (ii), which consists of identifying shareable reserved channels. We show in particular that the time-complexity of this operation, if deterministic, is proportional to the total number of reserved channels, and thus does not scale well when the number of lightpaths established in the network becomes large. We then present a stochastic approach to execute this operation with a certain probability of accuracy. We show that by trading a deterministic TRUE or FALSE statement for a PERHAPS statement with a measurable likelihood that PERHAPS is TRUE, the operation can be made independent of the number of reserved channels. The benefits of this substitution are: (1) reduction of the path computation time and (2) reduction of the amount of information necessary to compute the paths, with no penalty or small penalty in terms of capacity efficiency.

Section B develops the complexity of the deterministic approach to identify shareable channels. Section C describes the details of the stochastic approach. Section D describes an algorithm to compute mesh restored paths using the stochastic approach. Section E compares the results for realistic topologies using both stochastic and deterministic based algorithms, and Section F concludes this paper.

B. TIME COMPLEXITY OF DETERMINISTIC APPROACH

In what follows, a list of SRGs protected by a given reserved channel consists of all distinct SRGs traversed by all the primary lightpaths whose respective protection paths are assigned the reserved channel. Thus a reserved channel can be reused to protect a primary path if no SRG traversed by the primary path appears in the list of SRGs already protected by the channel. We denote by h the average primary path length expressed in number of edges, m the number of edges in the network, and x the number of reserved channels per edge. We also assume the typical case where the average number of protected SRGs per reserved channel is on the order of $O(m)$. In order to identify shareable reserved channels in the network the algorithm must verify for each reserved channel in each edge that the list of SRGs protected by the channel does not intersect with the list of SRGs traversed by a primary path p. Therefore, the complexity of identifying all the edges with shareable reserved channels in the network is $O(hxm^2)$. This complexity is simplified to $O(hxm)$ if each reserved channel maintains a fixed length array in which each entry indicates whether an SRG is used or not. The number of reserved channels per edge is a function of g, the number of lightpaths in the network, and can be approximated by $x=O(gh'/m)$, where h' is the average length of a backup path ($h' \geq h$.) Substituting x, the complexity of this operation is $O(ghh')$. Our primary concern here is the dependence of this complexity on the number of lightpaths established in the network. We thus propose to substitute this time consuming deterministic approach for a stochastic approach whose complexity remains constant with respect to the number of lightpaths.

C. STOCHASTIC APPROACH

In what follows, we assume that the RCM has an up-to-date knowledge of the state of the network. In particular this information must include for each fiber (i) the number of reserved channels in the fiber, and (ii) for every SRG in the

network the number of reserved channels in the fiber that the SRG appears in.

We now describe the technique used to quickly compute the probability that a reserved channel is shareable with respect to a given primary path and based on the information available to the RCM. We will first introduce a simple combinatorial problem, solve it, and show the analogy between this problem and the one that we are interested in.

1st. A Simple Problem of Combinations

The problem: We are given N bags tagged from 1 to N, filled with marbles. Bag j ($j \in \{1, ..., N\}$) contains n_j marbles. All marbles in any given bag have the same color, but marbles in different bags have different colors, so that there is a one-to-one mapping between bags and colors. We are also given M bins tagged from 1 to M. We assume for the moment that the bins have infinite capacity. Next we empty the bags in the bins, so that not two marbles of the same bag (or same color) fall in the same bin. The questions are:

1. How many differentiable combinations of marbles to bins are possible? Assume that we cannot distinguish between two marbles of the same color.
2. Out of all combinations computed in (1), how many of them have empty bins left?
3. What is the probability that at least one bin is empty? Assume that probability of occurrence is the same for all combinations computed in (1) and (2), i.e. the marbles are uniformly distributed in the bins.

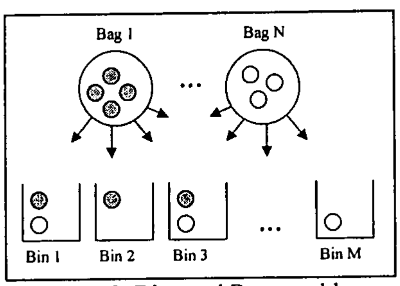

Figure 3. Bins and Bags problem

The answers:

In the following we use $C(p,q)=q!/p!/(q-p)!$ to denote the unordered combinations of p out of q elements.

1. First note that a solution exists iff $M \geq n_j \ \forall j \in \{1, ..., N\}$. The marble arrangement of each bag into the M bins is not conditional to other bags' arrangements. For each bag j there are $C(n_j, M)$ possible ways to arrange the n_j marbles into an ordered set of M bins. There are thus $Q=\prod_{j\in\{1,...,N\}} C(n_j, M)$ arrangements.
2. First note that if $\exists j \in \{1, ..., N\}/M=n_j$ then there is no such combination, and the answer is D=0. Note also that if $M>\sum_j n_j$ then we cannot fill all the bins and the answer is D=Q. If $M=1+\max_j \{n_j\}$, the problem is equivalent to (i), except that now arrangements are confined to M-1 bins, the last bin being left empty. They are thus $D = C(M-1, M)\prod_j C(n_j, M-1)$ possible arrangements. Otherwise, if $M>1+\max_j \{n_j\}$, $D=r(M-1)$, where r(k) is the recursion over integers in $k\in\{\max_j \{n_j\}, ..., M-1\}$ such that $r(\max_j \{n_j\}-1)=0$, and $r(k)=\{C(k, M)\prod_j C(n_j, k)\}-r(k-1)$. (See Appendix in Section G)
3. P=D/Q, although the computation of D and Q may be tedious. We thus show here a mean to approximate this probability. First observe that the probability that at least one bin is empty is complement to the probability that all bins are non-empty. And the probability that a bin is non-empty is the complement to the probability p that this bin is empty. Although p is conditional to the probability of other bins being empty we assume that it is independent and identical for all bins. Therefore, given a bin the probability p that the bin is empty is the product of independent probabilities that all marbles of each bag are in other bins, that is $p=\prod_j(1-n_j/M)$. Based on our observations and assumption, the probability that at least one bin is empty is $P=1-(1-p)^M=1-(1-\prod_j(1-n_j/M))^M$. The complexity of computing P (or its complement 1-P) involves computing N products and an M^{th} power. It is realizable in $O(N+\log M)\approx O(N)$ time.

2nd. Analogy with SRG arrangement into a set of reserved channels

Assume that the M bins of the problem presented in 1st are the reserved channels in a given fiber. And assume that the N bags represent a list of N SRGs traversed by the primary path for which a reserved channel is sought. The n_j marbles denote the number of times each SRG of the list is protected (through pre-established paths) by the reserved channel set. Evidently the same SRG cannot be protected multiple times by the same reserved channel otherwise contention would exist through their respective primaries if the SRG fail. This restriction is expressed in the problem formulation by the fact that two identical marbles (same SRG) cannot fall into the same bin (reserved channel). Thus, the problem above deals with computing the probability that there is at least one shareable reserved channel, i.e. a reserved channel that does not contain any of the N SRGs. We have shown that this probability is approximated in O(N) time, where N is the number of SRGs on the primary path. Typically N is the average path length *h*. Therefore, the complexity of identifying all the edges with shareable reserved channels in the network is $O(hm)$. This complexity is to be compared with $O(ghh')$ of the deterministic approach. Remember that in the computation of these probabilities we have made two simplifying assumptions: (i) the probability of a reserved channel being shareable is pair-wise independent of other reserved channels, and (ii) SRGs are uniformly distributed across reserved channels. The effect of the first assumption is easy to quantify by way of simulations (see Section E.) The effect of the second assumption on the other hand is subtler because it depends on the policy used for allocating reserved channels. For instance a "First Fit" or "Max Fit" policy tends to pack

(protect) more SRGs in some reserved channels than others within the same fiber. As it turns out, a First Fit policy increases the probability that a reserved channel is available compared to a uniformly randomized allocation.

D. ALGORITHM

We describe here in details an algorithm that implements the stochastic approach, and compare it with the equivalent deterministic algorithm.

Given: a topology represented as a graph G(V,E) where vertices represent optical cross-connects (OXC) and edges represent fiber strands between OXCs. A network state database, that indicates for each edge (fiber) the number of channels available, the number of reserved channels, and the number of times each SRG in the network is protected by a reserved channel in that edge. The latter information is stored into an array. The array's indices correspond to SRGs and each entry in the array counts the number of reserved channel cross-connections that would occur in the edge if the corresponding SRG fails.

Input: a pair of nodes A-Z

Output: a pair of bi-directional lightpaths from A to Z, primary and secondary with minimum cost, excluding restoration channels that are shared with pre-established backup paths.

Algorithm:

1. Compute k-shortest paths. Sort the paths by length and denominate them w_1 to w_k.
2. Set $S=\emptyset$
3. For each shortest path w_i, do:
   (i) To each edge that shares a SRG with w_i or has neither available channel nor reserved channel, assign infinite weight
   (ii) For each edge without a reserved channel, set weight to cost of edge
   (iii) For each edge with reserved channel, set weight to cost of edge times the probability that no reserved channel is shareable (by way of the approach presented earlier in section C of this document.)
   (iv) Compute the shortest path s_i using the metric defined in parts (i) to (iii), and set $S \leftarrow S+\{w_i,s_i\}$.
4. Select the minimum cost path pair $\{w_k,s_k\} \in S$.
5. Use signaling to set-up the path. Reserved channels are assigned locally, using some local optimization algorithm for instance. If no path can be found in 4 return NO_PATH.

The algorithm is self-explanatory. It differs from the deterministic algorithm only in step 3(iii). In the deterministic algorithm the weight of an edge is set to the edge cost times $\varepsilon \ll 1$ if it contains a shareable reserved channel and edge cost if it does not. In the stochastic algorithm this weight is replaced by the cost of the edge times the probability that no reserved channel is shareable in the edge. Note that the deterministic approach requires additional information to compute the routes. In particular it needs to know whether each SRG is protected or not for every reserved channel. Whereas in the stochastic approach, only the number of times an SRG is protected in every edge by any reserved channels of that edge needs to be known. Finally, note that in step 5 we separated lightpath provisioning from routing, and channel assignment is performed in a distributed way after the lightpaths are selected by the RCM. The objective of the RCM is to compute the paths so that sharing is maximized during channel assignment. Even though an edge may be erroneously tagged as having a shareable channel during path computation, the channel assignment procedure during path setup will guarantee that they are no sharing violation. In order to guarantee this, the scheme used for channel assignment requires the same information as for the deterministic approach, however this information can be distributed across the nodes in the network: it suffices that each node maintains a local database of all the reserved channels terminating into it.

For the experiments presented in the next section we used both the deterministic and stochastic implementations of the algorithm. A great care was taken in optimizing the deterministic implementation for speed. The stochastic code was then derived from the deterministic code by modifying step 3(iii) as described above.

E. EXPERIMENTS AND RESULTS

3rd. Accuracy and Distributions of Probability Functions

In the following we first measure the quality of the estimated probability that an edge contains a shareable reserved channel given the information on the number of times each SRG traversed by the primary path is restored in that edge. The experiment consists of simulating a large number of arbitrary instances of the problem presented in section 1st. For each instance of the problem, we simulate several millions of random arrangements, and compute the ratio of combinations with available reserved channels to the total number of combinations (i.e. estimate 1st.3) We then compare the difference between each experimental probability and the corresponding exact and approximate probabilities obtained by computation. The results are shown in Figure 4 and 5. Figure 4 demonstrates the error distribution of the estimate probabilities minus experimental probabilities obtained over the range of problem instances. We observe that the estimate probability has a tendency to underestimate the experimental probability, but it is accurate within 0.05 for 85% of the time, which is quite remarkable given the simplicity of the computation. In comparison, the simulation exhibits an accuracy within 0.01 of the exact probability, and a closer look even indicates that 70% of the time the difference is within 5×10^{-4} (Figure 5).

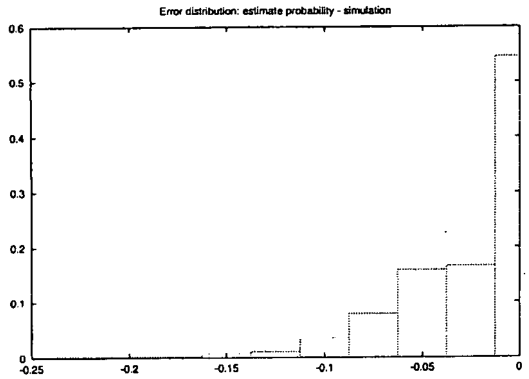

Figure 4. Error distribution of estimate sharing probability versus simulaion

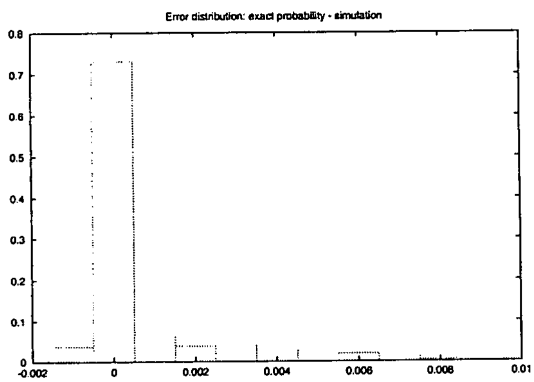

Figure 5. Error distribution of exact sharing probability versus simulation

4th. Comparison of Deterministic versus Stochastic Weight Functions on Real Networks

In the next set of experiments we consider two scenarios inspired from real life networks. NetA is a 100- node, 137-edge network, with one unit of demand between every pair of node (4950 demands). NetB is 220-node, 300-edge network, also with one unit of demand between every pair of node (24090 demands.) For the sake of simplicity we assume here that every edge costs one unit of currency and corresponds to one SRG (i.e. one SRG per edge and one edge per SRG). We then route the demands on each network using the deterministic and the stochastic algorithms. We are interested here in the processing time to complete each algorithm, and the quality of the solutions expressed in total number of channels required (used for primaries and reserved for backups.) Table 1 summarizes the results. For NetA (resp. NetB) we observe that the stochastic approach is 6.78 time faster (resp. 19.7 time faster) than the deterministic approach while the penalty is only 2% (resp. 3%) more capacity. Also important is the amount of information the RCM needs to compute the routes. The stochastic based RCM only require one array per edge, where each entry indicates the number of times the SRG is protected in the edge by any reserved channel. For instance in the NetB problem, they are 300 such arrays (one per edge) of 300 entries each (one per SRG). For comparison. The deterministic approach needs an array for each reserved channel, where each entry corresponds to an SRG and indicates whether the SRG is protected or not by the reserved channel. In the solution of the NetB problems, 213052 of the channels are reserved for protection, thus 213052 arrays of 300 entries would be required in the deterministic method.

	Time to complete (sec.)		
	Determ.	**Stoch.**	**Ratio.**
NetA	156	23	6.78
NetB	9885	501	19.7

	Usage (# channels)		
	Determ.	**Stoch.**	**%**
NetA	61312	62716	102%
NetB	520771	536343	103%

Table 1. Deterministic versus stochastic algorithm, summary of results

Finally Figure 6 plots the distributions of sharing probabilities as computed in step 3(iii) of the stochastic algorithm during the provisioning of the demand in NetA and NetB. The distributions are similar and show that70% of the time (77% in NetB) it was possible to determine almost certainly whether there would be a shareable reserved channel (probability 0.0 that an edge does not have shareable channel, 57% of the instances) or not (probability 1.0, 20% of the instances.)

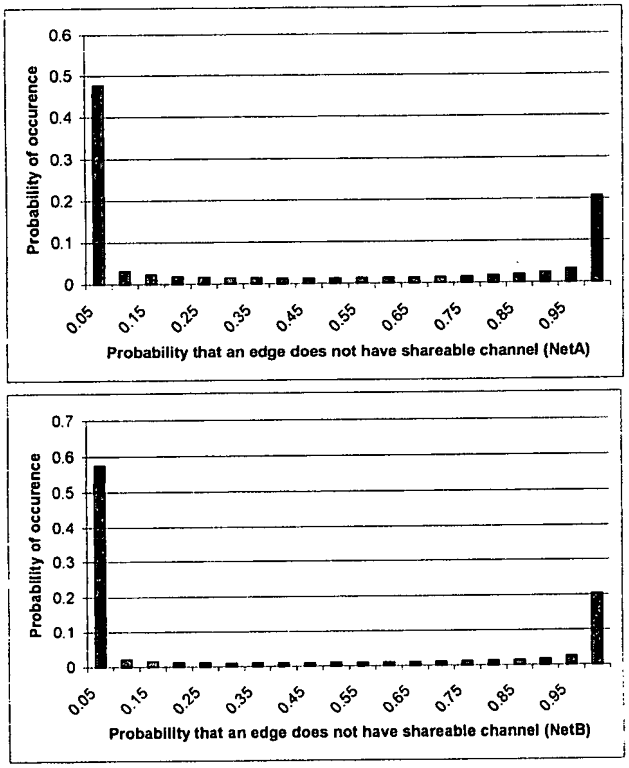

Figure 6. Distribution of Sharing Probabilities (NetA and NetB)

F. CONCLUSION

In this paper we describe a stochastic approach to identify shareable channels in a network when computing shared mesh-restored lightpaths. We show that a summarized information consisting of one fixed length array for every edge is sufficient to compute the paths efficiently while maximizing sharing opportunities. In contrast, the deterministic approach needs one such array for every protection channels, and thus does not scale when the demand grows.

Our results demonstrate that the stochastic approach completes the routing 6 to 20 times faster than the deterministic approach for networks ranging from 100 to 200 nodes. Although the stochastic approach uses several orders of magnitudes less information than what is necessary for a deterministic approach, their solutions are within 2% to 3% of each other in terms of capacity usage. In fact our experiments indicate that 70% of the time this little information is sufficient to determine with certainty whether a reserved channel could be shared or not.

One possible and natural application of the stochastic approach is for distributing the routing of shared mesh restored lightpaths to the optical switches. The local database of each switch may contain a summarized information that is necessary to compute the routes using the stochastic approach. Since this information is small, it can easily by dissimenated.by link-state protocols, such as OSPF. Using this information each demand's ingress switch can compute a path equivalent to a path computed by a centralized deterministic algorithm with a complete view of the network's state.

G. APPENDIX

In reference to question 2 of the problem presented in 1st, we show here how to compute the number of "non-blocking" combinations.

Let $r(\max_j n_j - 1)=0$, and $r(k)=\{C(k, M)\prod_j C(n_j, k)\}-r(k-1)$.

Case 1: if $M=\max_i n_i+1$ then there is at most one bin empty, and the answer is the number of solutions in the remaining M-1 bins. Thus $D = C(M-1,M)\prod_j C(n_j, M-1) = r(M-1)$, as expected.

Case 2: If $M>\max_i n_i+1$, then there may be up to $M-\max_i n_i$ empty bins. An incorrect answer would be to treat Case 2 in the same way as we treat Case 1, that is to remove 1 bin out of M, and compute all possible combinations in the M-1 remaining bins. In order to understand why this is incorrect, take the case $M=2+\max_i \{n_i\}$ and assume that we treat it as in Case 1. There can be up to 2 empty bins, and all combinations that have 2 empty bins will be counted twice, once for each of the two bins that is removed. Figure 7 illustrates this. The figure represents 3 bins, and one marble. If we remove one bin at the time and count the number of possible ways to place the marble in one of the two remaining bins, we observe that some combinations are equivalent. For instance, in combinations a) or b), c) or d) and e) or f) the marble respectively occupies the same position, but a different bin was removed. Therefore, although the computation in Case 1 would indicate 6 possible combinations, they are actually 3 of them. The argument presented in this simple example can be easily extended to cover the case of n marbles in M=n+2 bins. Observe now that if the number of combinations in (M-m) bins is known, then it is easy to derive from it the number of combinations in (M-m+1) bins. Let r(M-m) denote the number of combinations in (M-m) bins, then the number of possible combinations in (M-m+1) bins is $C(M-m+1,M)\prod_j C(n_j, M-m+1)$ minus the number of combinations in (M-m) bins that would otherwise be counted twice, that is $r(M-m+1) = \{C(M-m+1,M)\prod_j C(n_j, M-m+1)\}-r(M-m)$.
Replacing M-m+1 by k, one recognizes the recursion presented in 1st part 2.

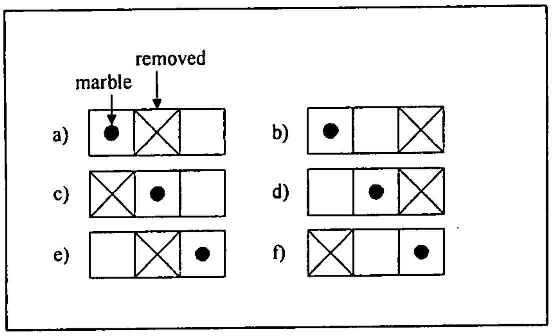

Figure 7. Combinations of 1 marble into 2 bins (out of 3 bins)

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